Development of Advanced Robotic Hand System for Space Applications

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KEY WORDS AND PHRASES

Robotics, robot hand, space robot, teleoperation, autonomy.

ABSTRACT

The Advanced Robotic Hand System(ARH) is a precise telerobotics system with a semi-dexterous hand for future space application. The ARH will be tested in space as one of the missions of the Engineering Tests Satellite VII (ETS-VII) which will be launched in 1997. The objectives of the ARH development are to evaluate the capability of a possible robot hand for precise and delicate tasks and to validate the related technologies implemented in the system. The ARH is designed to be controlled both from ground as a teleoperation and by locally autonomous control.

This paper presents the overall system design and the functional capabilities of the ARH as well as its mission outline as the preliminary design has been completed.

INTRODUCTION

The necessity of highly efficient, dexterous and versatile robot hands increases its importance for complicated and precise tasks of unmanned space facilities. To evaluate and validate related technologies of this kind of system, the Ministry of International Trade and Industry(MITI) has started the development of the ARH, which consists of a multi-degrees-of-freedom(DOF), multi-finger and multi-sensor robot hand and its supporting equipment.

The ARH will be experimented as one of the missions of the ETS-VII, which is developed by National Space Development Agency of Japan (NASDA), in order to evaluate key technologies such as dexterity and autonomy of robot hand control as well as to evaluate the capability for prospected in-orbit precise robot tasks.

Fujitsu, under the contract of MITI and under the supervision of related organization, has completed the preliminary design of the ARH. This paper reports the overall system design and functional capabilities of the ARH as well as its mission outline.

ARH SPACE EXPERIMENTS

The objectives of the ARH mission are to develop and evaluate the key technologies required for a next generation space robot which will be in charge of precise space tasks, and to validate the experimental robot system in which these technologies are implemented[1],[2]. To be more concrete, objectives are as follows:

1) Evaluate the capability of a multi-degree and multi-sensor robot hand dedicated to precise tasks required for unmanned systems or extra-vehicular activities(EVA).
2) Validate the space environment durability of mechatronic parts/devices for a space robot hand.
3) Master teleoperation skills and techniques under the communication restrictions such as limited communication capacity and time delay via a data relay satellite.
4) Acquire expertise of space robot control and operation in such space environment as weightlessness and visual monitoring restriction.

The concept of the space experiment system is shown in Fig.1.

The characteristic of the space experiments is that the ARH will perform experiments for about one and a half years in the exposed space environment and will be engaged in precise tasks with a multi-fingered robot hand. Although there was a similar mission, Rotex, it was a several day experiment in the pressurized module, and its hand is a 1-DOF gripper. So the ARH may be the first space robot hand for precise tasks in EVA.

The space experiments of the ARH currently planned are divided into two categories; one is the experiments performed by the ARH system only, the other is the experiments in which the hand is attached to another robot arm(ERA) that will be mounted on the same satellite and be developed by NASDA. The experiments of the ARH only are as follows: 1) electric connector mate/demate, 2) fastening and loosening a bolt, 3) capturing of a floating object, 4) solar cell and thermal blanket expansion and handling,5) electric wire manipulation. The experiments by the hand attached to the ERA are as follows: 1) electric connector mate/demate, 2) inspection and handling of a experiment sample.

SYSTEM DESCRIPTION

The resource assignment of the ARH is very limited because ETS-VII has other main missions such as rendezvous-docking experiment and the ERA experiment. Therefore, the ARH is required to realize and perform above mentioned experiments within the assigned resources of about 44 kg weight and 500 x 480 x 500 mm envelope. In accordance with these restrictions, the preliminary design of the ARH has completed. The picture of the functional model is shown in Fig.2. The system configuration and system specification are shown in Fig.3 and Table 1 respectively. The flight segment consists of a hand, a control unit, a mini-arm, a task board and a task panel.The ground segment consists of workstations, a hand operation device, and monitor displays which show computer graphic images and real TV camera images.

The system has three operation mode. One is a teleoperation mode. Another is an onboard semi-autonomous mode, in which the hand and arm are controlled by an onboard program with the position correction using various sensor data. As a third mode, shared control between teleoperation and autonomous operation is also tried in the experiment.

The Hand

The basic design requirements of the hand are 1) to enhance the dexterity and versatility by employing a multi-finger/ multi-DOF hand , and 2) to increase onboard autonomy using multi-sensors. The hand designed is shown in Fig.4.

Considering the first requirement, the hand is designed to have three fingers with three DOF. One of them is a linear driven finger, the other two are rotary joint fingers. An object is grasped by three fingers. One of the fingers has an adaptable mechanism on its surface. A passive compliance device is installed to absorb position errors of manipulator arm. These mechanism will enhance the handling versatility, reliability and operability while decreasing processing loads of the onboard computer. According to the second design requirement, proximity range fingers, a hand-eye camera, grip force sensors, a compliance sensor and a force-torque sensor are embedded in the hand. Proximity range finders are mainly used for approach control to the task board. A CCD hand-eye camera is used to find the mark on the task board, and its image data is processed by the computer to calibrate the position errors. These sensor fusion technique will enhance the sensor based autonomy, and give a secure and flexible manipulation.

The Experiment Stage

The experiment stage consists of the mini-arm and the task board. The mini-arm with length of around 70 cm has R-P-P-P-R joints of five degrees so as to assure adequate movements in the limited mass and space resources. Each actuator has a harmonic drive which realizes 0.5 mm position accuracy. At the end of the mini-arm the tool that detaches or attaches the hand in space is equipped. The task board consists of four experiment panels where experiment parts are equipped on them. All these parts are locked so as not to be detached when it is launched, and are unlocked by the hand when the space experiments start. The hand and the mini-arm are locked separately on the base plane of the experiment stage when they are launched, and are released when the space experiments start. This hand release mechanism is also used when the ERA attaches or detaches the hand for the ERA-ARH experiments.

The Control Unit

The control unit consists of the processing computer and the power supply. The computer uses Intel 80386/387 as its MPU, which is responsible to control the mini-arm and the hand, and to process multi-sensor data as well as telemetry/command data. The computer includes a DSP board for mini-arm servo control. The sizes of ROM and RAM in it are 128KB and 256KB respectively.

The onboard software realizes or assists space experiments depending on operational modes. Its structure is shown in Fig.5. The software consists of OS, experiment program interface functions, and experiment programs. This software architecture enables experiment users to write experiment oriented programs independently from the other software while keeping the system safety. The software allows to be reprogrammed from the ground according to operational needs. As joint control parameters in space will be totally different from those of the ground due to missing gravity, in-orbit calibration using various sensors will be required. Thus these parameters are also uploaded from the ground.

The data link between space and ground is, down-link wise, the computer of the ARH, the satellite communication equipment, the data relay satellite, the ground station and the ground control facility of the ARH. The communication rate of 800 bps (4Hz) is allowed for teleoperation command. The down-link rate is 1.5 Mbps which include compressed TV image and telemetry data. A total time delay of 2 to 4 seconds is expected for the data link.

The Ground System

The ground system has the function of the supervising space robot system as well as processing telemetry and command data providing operators necessary information by a model based simulation, which compensates communication time delay and limited onboard visual information. The computer graphic simulation displays images of 3-D solid-shaded polygonal rendering. The ground system configuration is shown in Fig.6.

An operator can manipulate the master control device to control onboard mini-arm and the hand as a teleoperation control assisted by the task visualization of preview and prediction, which enhances the operation safety and efficiency. In this mode the onboard computer adjusts small errors of modeling by feedbacking hand-eye camera and proximity range finder data. In another operation mode of the ground system, an operator sends pre-programmed commands that controls the hand and mini-arm autonomously. The hybrid operation of these two modes is supported by remote-end skill and local adjustment, which will be effective to accomplish precise and complex tasks. The ground system has monitoring functions of down-linked TV camera images as well.

SUMMARY

The outline of the Advanced Robotic Hand System and its mission is presented. Its preliminary design has completed and the engineering model is under development. The ARH is a small system in size, but it includes many key technologies of sensors, mechanisms and control architectures for advanced space robot performing precise tasks.

REFERENCES

[1] Machida, K. et.al.,1993. Preliminary Design of Advanced Robotic Hand for Space Experiment on ETS-VII. International conference of Advanced Robotics '93.

[2] Machida, K. et.al.,1993. Development of Dexterous Service Robot for Space Testing(1), The 11th Conference of the Robotic Society of Japan

Table 1. ARH Specification

Total system mass	44 kg
Dimension(Envelope)	500 x 480 x 500 mm
Average Power	85 W
Hand DOF	3
Grip force	20 N
Compliance	0.17mm/N(x,y),0.08mm/N(z),2.9deg/N
Mini-arm DOF	5
Accuracy	±0.5mm, ±0.5deg
Tip force	20 N
Communication rate	
Teleoperation command	800 bps
Real time telemetry	1.5 Mbps(including video data)
Mission period	1.5 years

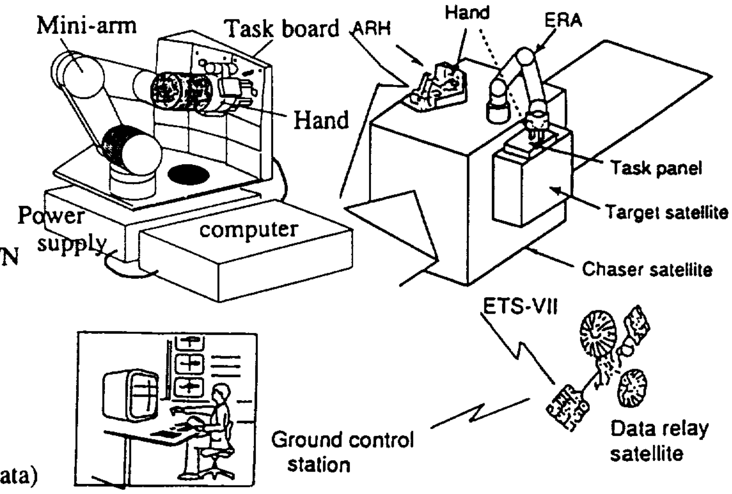

Figure 1. ARH System Concept

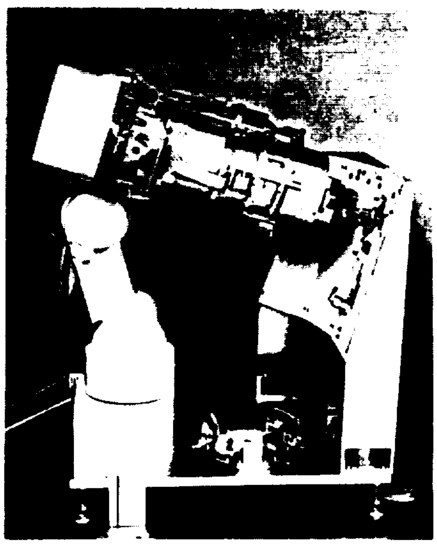
Figure 2. ARH Functional Model

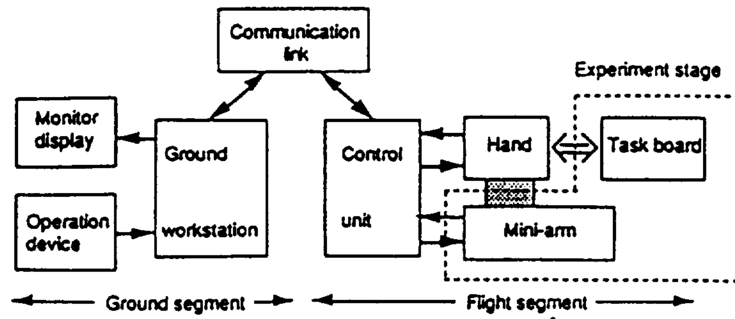

Figure 3. System Configuration

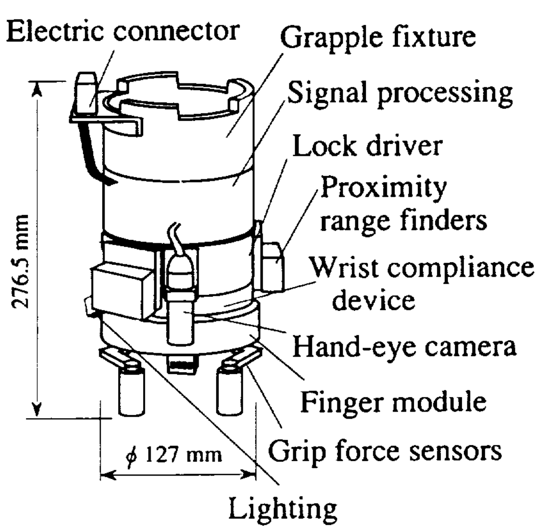

Figure 4. The Hand

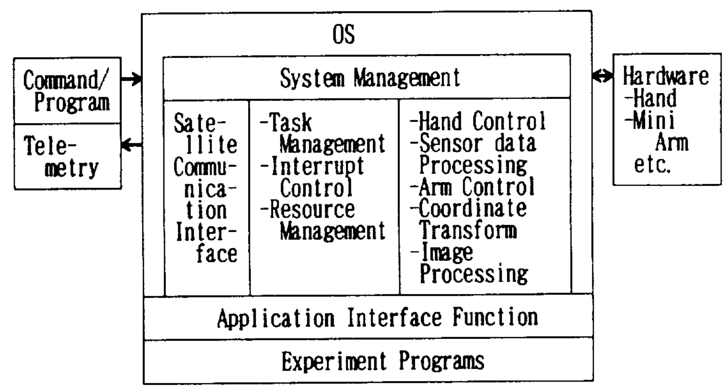

Figure 5. Onboard Software Structure

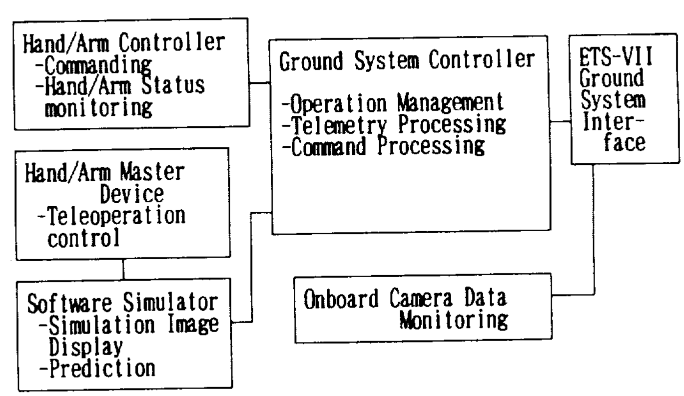

Figure 6. Ground System